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The effect of bulk microstructure and hydrogen specie on deuterium transport in tungsten

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In a future fusion reactor neutron irradiation will create displacement damage which influences material properties, such as material strain and strength. One of the options to improve the behaviour of the material is by changing the microstructure of the material. Here we have studied how bulk microstructure, i.e. grain size in the material, influences the accumulation of radiation damage in tungsten (W). The effect of microstructure on the generation of radiation damage was studied previously with W single crystal and polycrystalline W with grain sizes between 1 and 50 µm [1]. There, no significant effect was observed, with all samples showing similar D concentration in the damage zone. By using a laser-deposited, nano-crystalline W layer on a W substrate we proceeded with the study and went down with the grain size to the nanometer scale. The as-deposited layer had a grain size of few nanometers. By tempering, grain sizes of a few hundred nm up to few µm were adjusted. Samples were irradiated at 290 K by 20 MeV W-ions to create displacement damage down to 2.3 µm and with a maximum damage dose of 0.23 dpa. The concentration of defects was assessed by exposing samples to deuterium (D) atoms with an energy of 0.3 eV at 600 K and to 300 eV D ions at 450 K. We will report on the newest measurements performed by D ions and compare the results to atoms. In both cases D populates the created and existing defects. D retention and D depth profiles were measured by nuclear reaction analysis (NRA) utilizing D(3He,p)4He nuclear reaction. In the nanograined samples D populated the damaged region more than three times faster than the other two tempered samples. The concentration of defects was assessed by the final D concentration in the samples. Samples with smaller grain size showed larger D concentration in the irradiated area. However, large D concentration in the non-irradiated sample showed that defect density was already high in the initial material. Samples were also analysed by transmission electron microscopy to analyse the damage distribution in the material where nanometer-size voids were observed.

In the second part we will report on the effect of different exposure species (ions versus atoms) on permeation through tungsten. For this purpose, we have irradiated thin W foils by 20 MeV W ions on one side (downstream) and exposed the foils to D atoms of 0.3 eV energy and D ions with 300 eV energy on the other side (upstream) at 600 K and 700 K foil temperature. To prevent D atom or ion uptake on the downstream an additional protective Al2O3 (85 nm) layer with Ag (1 µm) spacer was deposited on the damaged side. We measured D depth profiles by NRA on the downstream side to track the permeated particles that were trapped in the damaged W layer. A very short "lag time" is observed in all cases. As expected, an increase in temperature to 700 K reduces the measured retention for the ion exposure due to thermal detrapping of D from the defects. Although this detrapping is also present for the atom exposure the higher temperature leads to a more efficient uptake at the surface which leads to larger measured retention as compared to the 600 K exposure. In both cases we observe no diffusion front visible but D concentration is raising within damaged layer homogeneously which could be explained by grain boundary diffusion.

[1] Pečovnik, M. et al. Influence of grain size on deuterium transport and retention in self-damaged tungsten. Journal of Nuclear Materials 513, 198–208 (2019).

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